Heliophysics White Paper

Artemis, Gateway, the return to the Moon and forward to Mars for Heliophysics

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Key Points:

1. **Artemis provides a unique opportunity for heliophysics and space weather**
2. **The frequent return to the lunar environment itself provides new science questions we heliophysics can address from the ancient Sun, to interactions with the surface, and impacts on our technology and humans living and working in space.**
3. **The Gateway and the Moon provide new platforms from which heliophysics and space weather observations can be obtained.**
4. **The regular return of humans to the Moon will allow for more data to be collected and returned to Earth.**
5. **We need to use the lunar expeditions as tests and opportunities to prototype new autonomous space weather tools for use on Mars.**

1 Introduction

Over a 100 years ago we humans first landed on Antarctica. At the time we could not have imagined the heliophysics scientific gains that would be got from this continent. Sixty-five years ago we had the first international geophysical year aimed at deployment of instrumentation across this southern most continent and around the globe in recognition of the potential advancements from this integrated system of measurements. This potential has been realized and continues to grow as Antarctica returns science results across most disciplines, inspires artists and athletes, and has touched the lives of many through these gains.

Today we are on the precipice of a future new Antarctica with the launch of Artemis 1 and plans for the return of humans to the lunar surface and human exploration to Mars. Heliophysics and space weather are necessary components for the success of these dreams and will benefit greatly from the fundamental science exploration that Artemis and mission to Mars will enable.

Within this paper we will discuss the ways in which Artemis and the mission to Mars will benefit Heliophysics and space weather and end with recommendations for steps we see needed to actualize these dreams.

2 CLPS missions

The Commercial lunar Payload Services is a collaboration between NASA and industry enabling rapid acquisition of lunar delivery services from American companies for payloads that advance capabilities for science, exploration, or commercial development of the Moon. Currently there are 14 vendors who will deliver both commercial and science payloads to the lunar surface. The CLPS missions are regularly competed and are a new and growing opportunity for science on and from the Moon.

Heliophysics is starting to take advantage of this opportunity through experiments like lunar Environment Heliospheric X-ray Imager (LEXI PI'd by Dr. Walsh from Boston University). LEXI is an example of how heliophysics can use the unique location of the Moon to look back at Earth. The Moon provides a unique vantage point to image the interactions between the solar wind and the magnetosphere. There are current technological challenges such as dust buildup, long cold nights, and currently inaccessible. However many of these are likely to change or be mitigated as the Artemis program continues.

These early CLPS launches are some of the first steps for heliophysics to explore this new field site. CLPS will further teach us how to operate in the lunar environment - partnering with industry, and start seeing the scientific gains it will bring.

Recommendation:

- NASA Heliophysics SMD work closely with the CLPS mission calls to help inform the heliophysics community about these opportunities.
- NASA Heliophysics SMD provide funding opportunities for missions to make use of the CLPS opportunities.

3 The Gateway

A space station will be placed in a Near Rectilinear Halo Orbit (NRHO) around the moon, providing an exceptional opportunity to host solar remote sensing and *in situ* payloads on a unique space platform. This station, named Gateway, will serve as a critical outpost for astronauts traveling between Earth and the lunar surface and as a platform for various low-mass internal and external experiments, thus already being equipped with power and telemetry capabilities. While Gateway is significantly smaller than the International Space Station (ISS), astronauts are only onboard for short periods with months of vacancy in between Artemis missions. Consequently, the Gateway vibration environment is considerably less “noisy" than the ISS, which is an advantage for many instruments that can be operated autonomously or remotely from Earth (e.g., those with tight pointing stability requirements).

Gateway will spend a small portion of each lunar month inside the Earth’s magnetosphere and experience deep space conditions otherwise, providing an unprecedented opportunity to explore the transition across these boundaries. space weather and fundamental heliophysics exploratory missions alike would greatly benefit from probing the diversity between the radiation, dust, plasma, and magnetic field conditions in these environments. Plus, the crewed Artemis missions provide a unique option for direct access to these deep space instruments in between periods of autonomous/remote operations.

Figure 1: Artist conception of Gateway in orbit around the moon with an approaching Orion vehicle. Credit: NASA/JSC

NASA’s Heliophysics Environmental and Radiation Measurement Experiment Suite (HERMES, led by Project Scientist Dr. Paterson at Goddard Space Flight Center) will be the first of two initial heliophysics payloads hosted externally on Gateway, along with the European Radiation Sensors Array provided by ESA. Both instruments will measure energetic particles carried in the solar wind.

In addition to the orbiting station, the logistics modules (LMs) that are used to shuttle equipment to Gateway will have (limited) additional capability to host experiments and other scientific instruments. When each LM mission is complete, there is the potential to eject the module into a heliocentric orbit with heliophysics payloads in tow. CubeSat deployment is another alluring potential option from Gateway or from an LM.

Recommendations:

- NASA Heliophysics SMD engage with the Gateway program in earnest to inform design requirements for 1) payload hosting on Gateway, 2) payload hosting on logistics modules for extended LM mission periods (i.e., power, telemetry, and positioning), 3) and payload deployment.
- NASA Heliophysics SMD provide funding opportunities for missions to make use of Gateway opportunities, in close coordination with the Gateway Program Office as it is evaluating its 15-year outlook.

4 Ride along opportunities

With more regular launches to the Moon, there is a unique set of opportunities for ride-alongs. Payloads will be able to be ejected or collect data along the path out to the Moon, go into lunar orbit, or ride out to other locations within the solar system as they leave lunar orbit.

A CubeSat to Study Solar Particles (CuSP PI'd by Dr. Desai from South West Research Institute) is an example of such a mission opportunity. CuSP is launching with Artemis 1 and will be "dropped off" on its way towards L1 and the Sun. This mission will study the solar wind and give us an understanding of how measurements from a CubeSat can help inform future astronauts and us here on Earth about incoming space weather.

As we accelerate our launches to the Moon - more opportunities will become available for CubeSats and smallSats. The launch to lunar orbit provides access to more unusual orbits - enabling us to move more frequently beyond low Earth orbit. This will allow us to explore more science questions such as CubeSats accessing more easily deep space including the radiation belts, the magnetotail, lunar orbit, and the heliosphere.

Recommendation:

- NASA Heliophysics SMD engage with the exploration systems development mission directorate to identify ride along opportunities which can further enable a diversity of CubeSat and smallSat orbits.
- NASA Heliophysics SMD provide funding opportunities for missions to make use of ride along opportunities.

5 LunaNet

LunaNet is the concept for the communication relay around the Moon and beyond. The basic idea is to have enough nodes to provide Earth based internet quality for uploads and downloads. This infrastructure could revolutionize space based missions. Historically, many satellite missions could have benefited from increased down-link [see position paper Expanding the Deep Space Network to support the Heliophysics System Observatory by Schofiled et al]. Using innovative technology and a Delay/Disruption Tolerant Networking (DTN) will increase our data collection - regardless of if the mission is associated with Artemis or not.

The construction of this space communication infrastructure provides a unique opportunity which we must take advantage of. LunaNet node, like many commercial and NASA missions, could potentially host science and space weather instrumentation. However, we must start planning and having discussions now as this infrastructure continues to develop. **By engaging at the beginning, we can ensure that our instruments are not an afterthought, and that the platforms can accommodate our needs.**

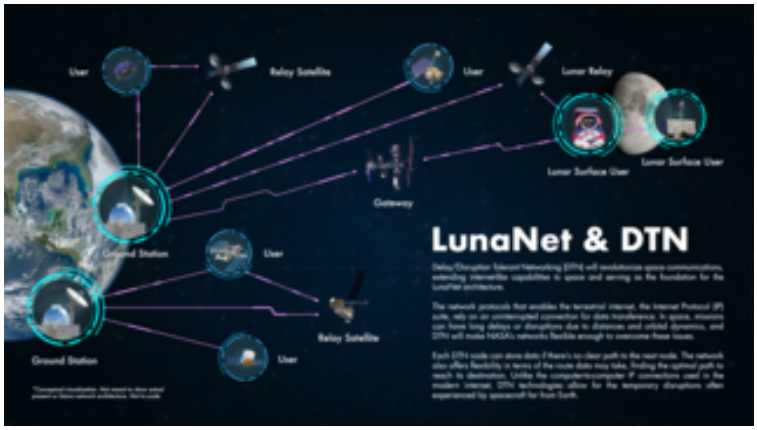

Figure 2: The LunaNet DTN concept graphic Credit: NASA/Reese Patillo

Recommendation:

- NASA Heliophysics SMD engage with the SCaN and the development of LunaNet in earnest to inform design requirements for 1) payload hosting on LunaNet nodes, 2) space weather payload hosting to accompany search and rescue modules for extended mission periods (i.e., power, telemetry, and positioning), 3) and payload deployment.
- NASA Heliophysics SMD provide funding opportunities for missions to make use of LunaNet opportunities, in close coordination with the SCaN as LunaNet becomes a reality.
- NASA Heliophysics SMD work with SCaN to identify opportunities where Heliophysics missions may be able to host, participate, and benefit as a LunaNet node.

6 Artemis Base camp

Artemis Base Camp is where the Astronauts will spend much of their time on the surface. It will also be their shelter from space weather including radiation storms. A base camp will enable the deployment and hosting of many surface platforms wheather they are lidars to study the lunar Exosphere, magnetometers to study remnant magnetic field interactions with the magnetosphere and the solar wind, or other long term instrumentation. So while from a fundamental science side we should consider and work with the development of the base camp as we do McMurdo, South Pole, and other field sites such as Poker Flat, we should also make sure that we inform where appropriate the design to inform about space weather hazards, and ensure that sufficient instrumentation to inform us about long term space weather hazards on the lunar surface is collected.

Figure 3: Illustration of NASA astronauts on the lunar South Pole. Credit: NASA

Recommendation:

- NASA Heliophysics SMD engage with the The development of the Artemis Base Camp in earnest to inform design requirements for 1) payload hosting on and around the base camp, 2) space weather payload hosting to accompany environmental health and search and rescue modules for extended mission periods (i.e., power, telemetry, and positioning), 3) and payload deployment for these resources.

7 Surface expeditions

Antarctica, like the Moon, has struggled with consistent power sources. While current tech development is working towards improving battery capabilities, we can learn how to mitigate this issue from our experience in Antarctica. Historically, instrumentation in Antarctica used solar panels and large batteries. However, systems typically ran out of power prior to the Sun rising again, or field teams reaching the site and removing the snow from the panels.

Figure 4: Artist conception of how LunaNet will enable clear communication and images along with actionable messages to astronauts on the lunar - and eventually Martian - surface. Credit: NASA/Reese Patillo

While we do not yet have humans on the Moon, we expect to have astronauts returning at least once a year - similar to the scientific pilgrimage to Antarctica every southern summer. Astronauts likewise could have the ability to go out and visit instrumentation field sites. During these expeditions they could replace batteries, grab stored data, replace systems, and more. However, this will take early planning with the planetary division to organize astronaut time

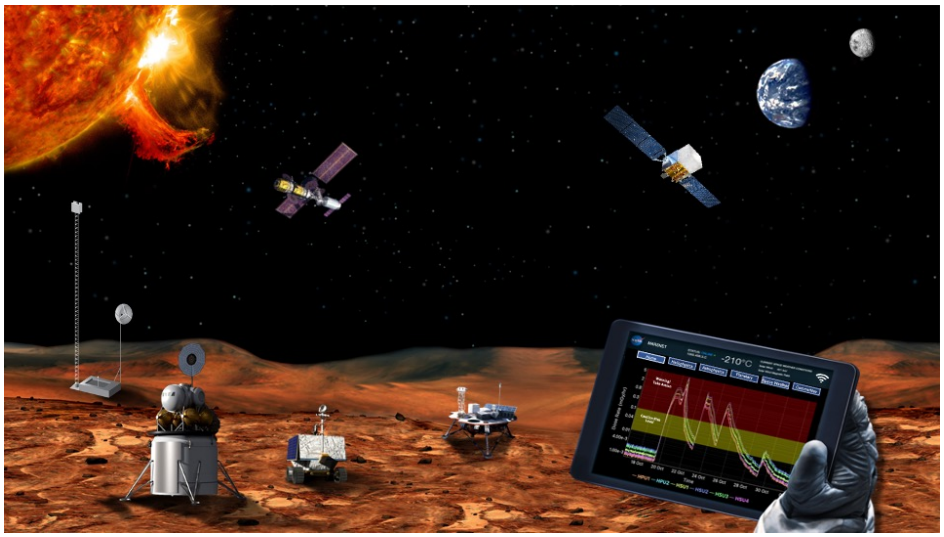

Figure 5: Conception of a Martian infrastructure and expedition.

and expeditions. It will also take planning for weight requirements, astronaut training for working with the instrumentation, and training for experimentalists to know how to make instruments that are safe to be handled by astronauts.

An additional component of surface expeditions as to the Artemis Base Camp is the need for space weather tools to inform astronauts about the environment and any incoming or local space weather hazards. Forecast and nowcast tools will be needed to help assess the risk of surface expeditions.

Recommendation:

- NASA Heliophysics SMD engage with planing of surface expeditions payload deployment and servicing
- NASA Heliophysics SMD engage with planing and funding for space weather tool development for human exploration.

8 Preparing for Mars

During this coming decade we to prepare for humans to go beyond Earth and the Moon and work on Mars. Beyond the infrastructure that will need to be built, autonomous space weather tools need to be developed. The autonomous tools will be needed due to the communications delay for Mars missions. To ensure the usefulness and reliability of the tools, they should be tested on the Moon where constant communication with Johnson Space Center is available. By working with astronauts both on the ground and in the field on the Moon, we will be able to tailor our tool development to provide actionable information about the space environment and hazards astronauts will face.

Additionally, the Artemis program provides opportunities for our community to learn how to develop and deploy tools which could be used in Martian explorations. We are unlikely to have

frequent expeditions to Mars so we must take advantage as they come. Mars will enable further investigations such as comparative atmospheres and ionospheres. We must start to plan for the deployable and surface based infrastructure which may benefit from human deployment, servicing, or human manipulation.

Recommendation:

- NASA Heliophysics SMD engage with planing of surface expeditions payload deployment and servicing
- NASA Heliophysics SMD engage with planing and funding for autonomous space weather tool development for human exploration.
- NASA Heliophysics SMD should engage with exploration systems development mission directorate and specifically SRAG to test space weather warnings and tools during lunar expeditions to prepare for future Mars expeditions.

9 Martian activities for the 2034 Heliophysics decadal survey

The Artemis program and the Moon to Mars program has developed quickly between the previous decadal survey and now. We need to ensure that as the opportunities come up we are flexible and able to adapt to the changing landscape. Artemis I is set to launch in later 2022 with Artemis II in 2023 and Artemis IV shortly after. The Mars human exploration missions will likely follow in the 2030's - but will need planing starting today.

Recommendation:

- Ensure that Heliophysics decadal activities include preparing for Human exploration of Mars and beyond

10 Recommendations for today

Heliophysics SMD can help enable Artemis activities and be enabled by humans return to the Moon. Artemis is full of potential, we just need to take it. This will take strengthening our SMD relationship with exploration systems development mission directorate, space technology mission directorate and other directorates and divisions within NASA. Historically we have had strong relationships with the Space Radiation Analysis Group (SRAG) - however, we now need to expand and reach out to new groups. For example, the Planetary division has many existing relationships with groups at Johnson who work with training astronauts to work with scientific instrument. We should work across the SMD divisions to strengthen our relationships across the agency to ensure the success of Artemis, and that Artemis lives up to its potential to enable generational leaps in our understanding of the heliosphere and how humans can live and work in space.

Work across NASA directorates to ensure Artemis lives up to its potential.